Preliminary results of equatorial wave experiment conducted from 18 Jan. 1999 to 5 Mar. 1999 with lidar at Gadanki

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An experimental campaign has been conducted from 18 Jan. to 5 Mar. 1999 at Gadanki using MST radar and lidar to delineate the characteristics of equatorial waves. In this paper, the preliminary results from lidar data on temperature in the upper stratosphere and mesosphere are presented. The characteristics of equatorial waves with periods in the range 9.4 days - 2.6 days in temperature are delineated.

I Introduction

In the equatorial stratosphere and mesosphere, the variability of the mean zonal wind is dominated by long period oscillations, namely, the quasi-biennial oscillation (QBO) and the semi-annual oscillation (SAO). While the former dominates in the lower stratosphere\(^1,2\), the latter dominates in the upper stratosphere and mesosphere\(^3\). The SAO peaks at stratopause level decaying to a minimum near 60 km and it increases again to a second peak around mesopause; the stratopause and mesopause SAOs are approximately out of phase\(^4\). The maintenance of these long period oscillations in the equatorial middle atmosphere has been explained in terms of selective wave propagation and wave-mean flow interaction. Equatorial Kelvin and Rossby gravity waves are mainly responsible for the westerly and easterly phase of the QBO (Ref. 5). For SAO, fast Kelvin waves which undergo negligible dissipation at lower levels are believed to be responsible for its westerly phase, while mean advection of easterlies across the equator at the solstices is thought to account for its easterly phase\(^6\). Recently the role of gravity waves has been emphasized in the SAO, especially, in its westerly phase\(^7\).

In all the theoretical models developed to explain the equatorial QBO and SAO, a great uncertainty exists in terms of lack of adequate information on the causative wave momentum fluxes. While considerable evidence accrued over the years on the existence of the equatorial waves\(^1,5\) from different experiments carried out over the years, there is a great paucity of experimental data on wave momentum fluxes\(^6,11\). This is mainly because of the requirement of vertical wind/temperature measurement with adequate altitude (and temporal) resolution for the determination of wave momentum fluxes. There had been practically no measurement technique for vertical wind and for temperature in the stratosphere and mesosphere with necessary temporal and altitude resolutions till recently. While rocket experiments can provide temperature data in the stratosphere and mesosphere, the temporal resolution (the rocket data are available at weekly intervals) and altitude resolution are not quite adequate for delineating various equatorial wave components and their momentum fluxes. With the advent of MST radar and lidar, it has now become possible to carry out these measurements.

At Gadanki (13.5° N, 79.2° E), a MST radar and a
lidar have been established providing the capacity for vertical wind and temperature measurements. An experimental campaign has been conducted during 18 Jan. 1999 - 5 Mar. 1999 to delineate equatorial waves in temperature using MST radar and lidar. The former gives temperature profile in the troposphere and lower stratosphere and the latter in the stratosphere and mesosphere. This campaign is the first step in the direction of experimental determination of wave momentum fluxes. The results of a preliminary analysis of lidar data for the detection of equatorial waves are presented in this paper.

2 Lidar experiments at Gadanki

The lidar employs a Nd:YAG laser operated at the harmonic wavelength of 532 nm with an average power of ~6.3 W, pulsewidth of 7 ns and a pulse repetition frequency (prf) of 20 Hz. The lidar was operated continuously from ~2200 hrs IST to 0500 hrs IST on all the nights during 18 Jan-5 Mar. 1999. The lidar backscattered signal above ~27 km is treated as completely due to air molecules and the temperature profiles were derived using the procedure of Chanin and Hauchecorne. One temperature profile is derived from backscatter data of 250 s (corresponding to 5000 laser pulses) with an altitude resolution of 900 m. Such profiles are averaged over the night to obtain the average temperature profile for each night. The number of profiles averaged for different nights varied between 70 and 100.

These average night profiles from 18 Jan. 1999 to 5 Mar. 1999 are arranged as a time series at 900 m altitude intervals. There is a total of 3 nights gap in the data (not continuous) and these are filled by linear interpolation. Thus, the time series comprise a length of 47 days. These time series at 900 m intervals are subjected to Fourier transform to obtain the amplitudes and phases of the periodic components. As the length of the data is 47 days, the frequency resolution of the Fourier transform is 1/47 day⁻¹.

Before presentation of the results of the analysis, the errors involved in the data and results are discussed in brief. The temperature profiles for each night obtained as average over the duration ~2200 hrs - 0500 hrs IST. The error in this average profile is estimated to be ~3 K at the highest altitude (of the profile) 70 km and decreases with decreasing altitude to ~1.5 K at 30 km (Ref. 14). As the Fourier transform analysis is done using a total of 47 data points, their error is further reduced by a factor of √(47/2) ≈ 4.8. Thus, the error at ~70 km can be put at ~0.6 K which reduces to 0.3 K at 30 km.

The amplitudes of the periodicities obtained from the FFT analysis are presented in the form of a contour plot in Fig. 1. The maximum and minimum periods that could be delineated are 47 and 2 days, respectively. Fairly large amplitudes appear at longer periods >15.7 (47/3) days. Because of the limitations in the data length (being only 47 days and hence only 3 cycles are covered for 15.7 day periodicities and less than 3 for longer periodicities) these amplitudes can only be taken to indicate presence of these long periods in the data. So deduction of any characteristics of these periodicities is not attempted here.

Two features are obvious from the contour plot. These are:
1. In the region around stratopause (40-60 km), fluctuations in the period range 5.2-2.8 days are weak.
(ii) In general, the fluctuation amplitudes are quite high in the upper mesospheric region indicating an upper mesospheric build up of the fluctuations. In Figs 2-5, are presented the amplitude and phase profiles of the 9.4, 5.2, 3.1 and 2.6 periodicities, which are the prominent ones observed. The thick line in the left-hand side panel in these figures denotes the profile of square root of atmospheric density ($\sqrt{\rho}$). As the amplitude of the waves grows in proportion to $\sqrt{\rho}$ in the absence of any attenuations, this profile helps to identify any growth or otherwise of the waves.

In the following, the salient features of the four significant periodicities obtained are presented.

(i) The 9.4 day periodicity:—The amplitude and phase of this periodicity is shown in Fig. 2. The amplitude is more or less steady with altitude in stratosphere. However, in mesosphere it is much less than what is indicated by $\sqrt{\rho}$ profile. This implies attenuation of the wave in the mesosphere. Between 80 and 65 km downward phase propagation is clearly seen with a vertical wavelength of ~22 km. Below this altitude range the phase is steady and indicative of the source region.

(ii) The 5.2 day periodicity (Fig. 3):—The amplitude is more or less steady around 1K with altitude in the stratosphere. It shows an increasing tendency in mesopause, but is less than that shown by $\sqrt{\rho}$ indicating attenuation. Below stratopause, the phase indicates a downward propagation with a wavelength of ~10 km. However, in the mesopause the phase does not reveal any clear propagation trend.

(iii) The 3.1 day periodicity (Fig. 4):—The amplitude is
steady in the stratosphere and increases in the mesosphere especially in the upper mesosphere. However, it is much less than that indicated by \( \nu_p \). The phase indicates more or less a downward propagation in mesosphere with a vertical wavelength of ~23 km. This is a remarkable feature indicating that this wave (of periodicity 3.1 days) propagates in the entire region of mesosphere. In the stratosphere the phase shows fluctuations.

(iv) The 2.6 day periodicity (Fig 5): - The amplitude follows more or less \( \nu_p \) profile except in upper mesosphere where it is less, indicating attenuation. The phase shows clear downward propagation below 60 km with a vertical wavelength of ~23 km. Above 60 km also it shows downward propagation but with a longer vertical wavelength

3 Summary and conclusions

(i) Temporal fluctuations in temperature build up to a very significant amplitude in mesosphere.

(ii) Equatorial waves in temperature with periods around 9.4 days, 5.2 days, 3.6-2.1 days could be delineated.

(iii) The 9.4 day periodicity wave propagates in the mesosphere with a vertical wavelength of ~22 km, whereas the 5.2 day periodicity wave shows propagation in the stratosphere with a vertical wavelength ~10 km.

(iv) The shorter period waves (3.6 - 2.1 days) show propagation in the upper stratosphere to mesosphere with a vertical wavelength of ~23 km.

(v) The four periodicities identified in the range 9.4 days-2.6 days show attenuation in the mesosphere.

(vi) Finally we conclude that lidar (operated in Rayleigh scatter mode) is capable of providing temperature data for the study of equatorial waves (of periods of a few days). It is for the first time that the equatorial waves in temperature are delineated in the entire altitude region of ~30 km to 80 km.

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